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(54) **BATTERY CHARGE CONTROL APPARATUS**

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(58) **Field of Classification Search**
USPC 320/104, 150–154
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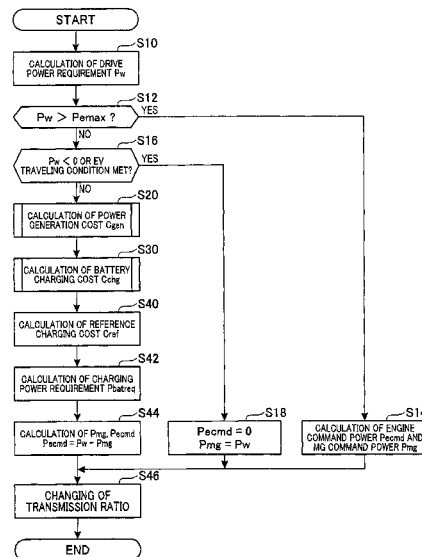
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(57) **ABSTRACT**

A battery charge control apparatus for a vehicle, where the vehicle is provided with a prime mover driven by using fuel stored in the vehicle, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a secondary battery that stores the electrical energy generated by the power generation means. The apparatus includes temperature detection means for detecting a temperature of the battery, and battery-charge limiting means for limiting storing of the electrical energy generated by the power generation means into the battery when the temperature of the battery detected by the temperature detection means is low. This leads to enhancement of fuel usage efficiency of the engine.
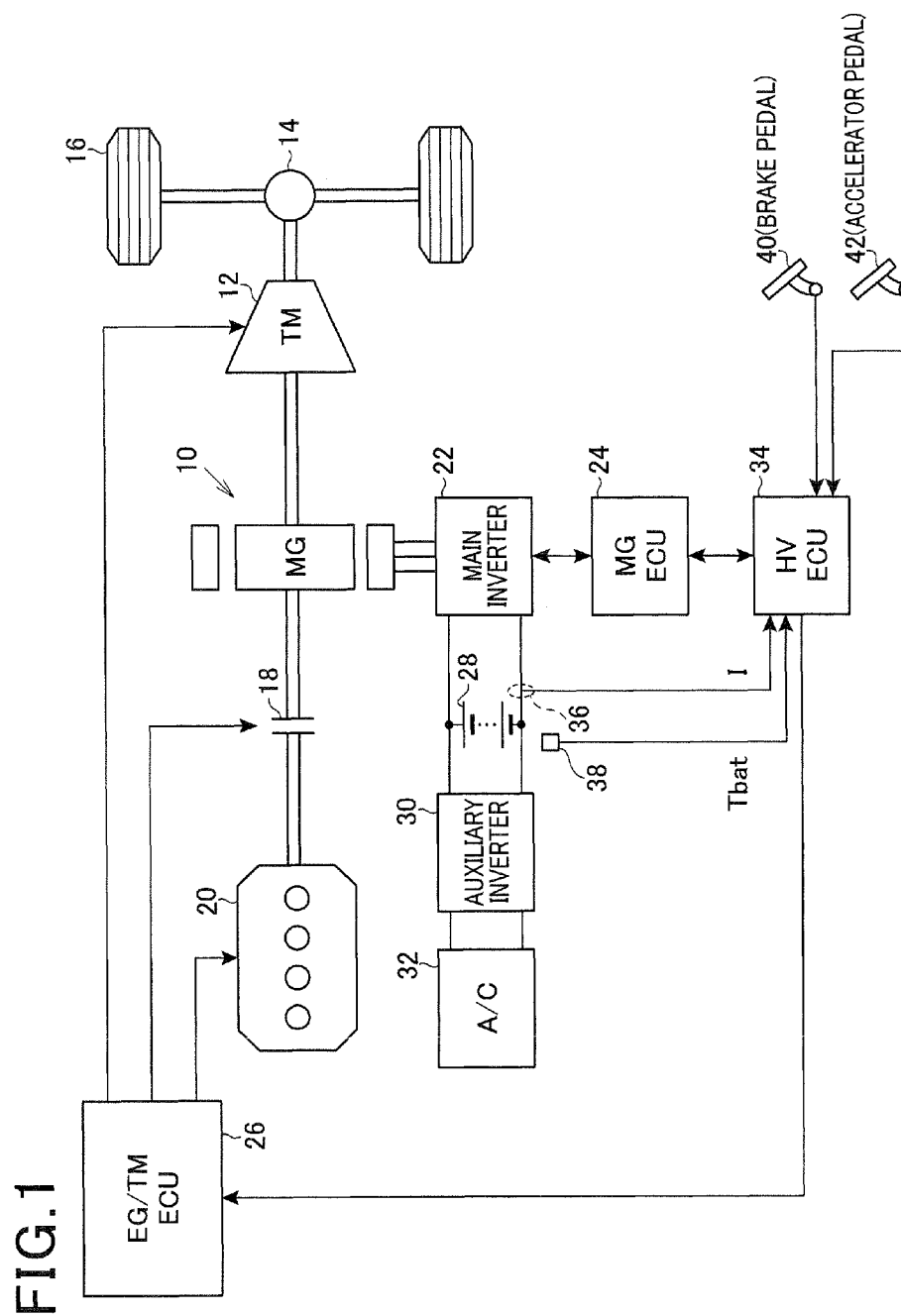
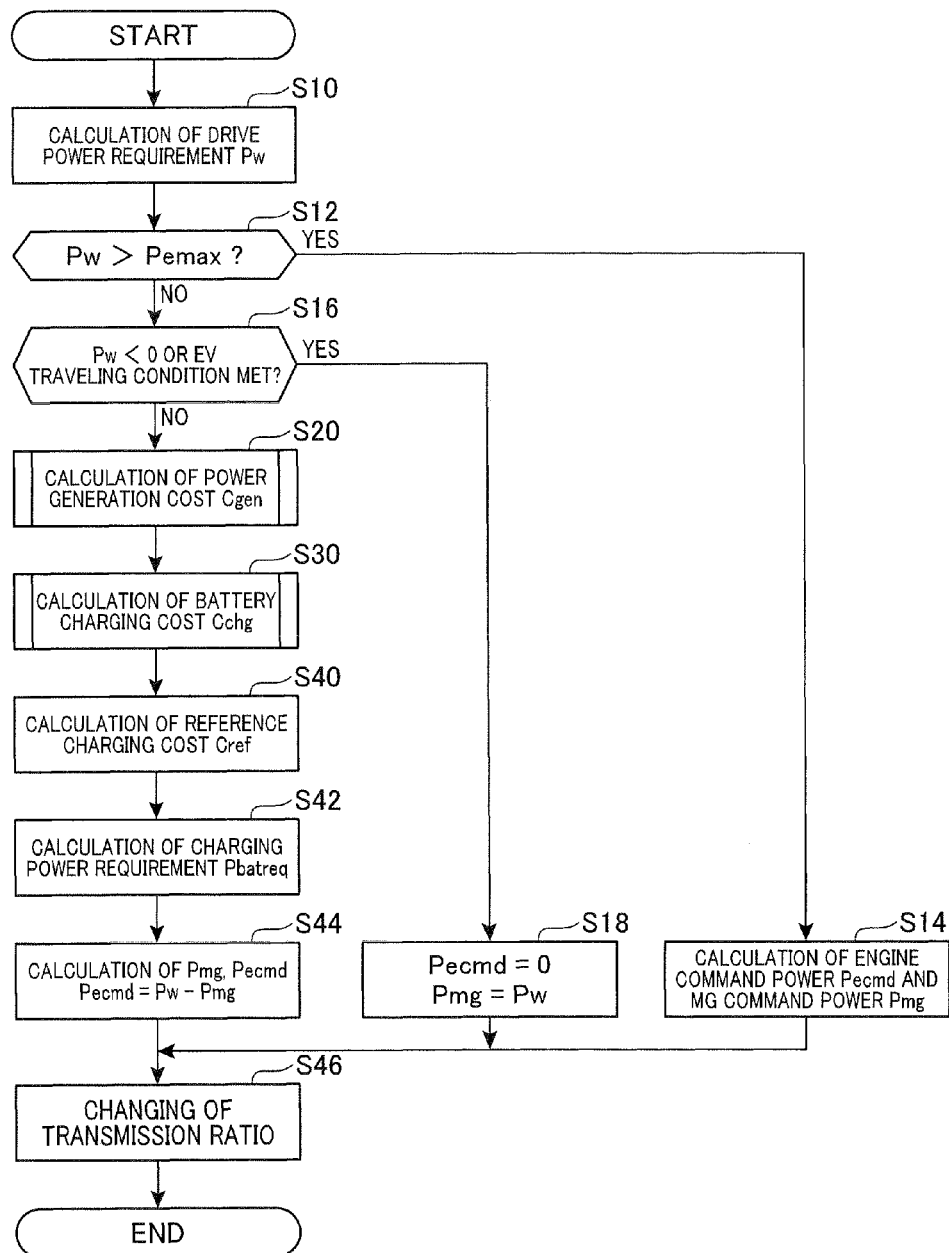**2 Claims, 6 Drawing Sheets**

FIG.1

FIG.2

START

$\sim$S10

CALCULATION OF DRIVE
POWER REQUIREMENT Pw

$\sim$S12

$Pw > Pemax$? — YES

NO

$\sim$S16

$Pw < 0$ OR EV
TRAVELING CONDITION MET? — YES

NO

$\sim$S20

CALCULATION OF POWER
GENERATION COST Cgen

$\sim$S30

CALCULATION OF BATTERY
CHARGING COST Cchg

$\sim$S40

CALCULATION OF REFERENCE
CHARGING COST Cref

$\sim$S42

CALCULATION OF CHARGING
POWER REQUIREMENT Pbatreq

$\sim$S44

CALCULATION OF Pmg, Pecmd
$Pecmd = Pw - Pmg$

$\sim$S18

$Pecmd = 0$
$Pmg = Pw$

$\sim$S14

CALCULATION OF ENGINE
COMMAND POWER Pecmd AND
MG COMMAND POWER Pmg

$\sim$S46

CHANGING OF
TRANSMISSION RATIO

END

FIG.3A

DRIVE TORQUE REQUIREMENT

ENGINE-DRIVEN MODE

EV-TRAVELING
MODE

TRAVELING SPEED

FIG.3B

Pref

LARGE

SMALL

Creq

SOC

100

FIG.3C

Cchg

Creq

Pchgmax(Tbat, SOC)

Pbat

Pbatreq

FIG.4

```
( CALCULATION OF POWER GENERATION COST Cgen )
                        │
                        ▼
┌─────────────────────────────────────────────┐
│ ACQUISITION OF LOAD POWER REQUIREMENT Preq   │──S21
└─────────────────────────────────────────────┘
                        │
                        ▼
┌─────────────────────────────────────────────┐
│     MG POWER OUTPUT Pgen ← Preq              │──S22
└─────────────────────────────────────────────┘
                        │
                        ▼
┌─────────────────────────────────────────────┐
│     CALCULATION OF MG POWER REQUIREMENT      │──S23
└─────────────────────────────────────────────┘
                        │
                        ▼
┌─────────────────────────────────────────────┐
│     CALCULATION OF SPECIFIC FUEL             │
│        CONSUMPTIONS FA, FB                   │
│                                              │──S24
│            TM OPERATING LINE                 │
│   TORQUE                                     │
│                                              │
│        B                                     │
│      A                                       │
│     ENGINE REVOLUTION SPEED                  │
└─────────────────────────────────────────────┘
                        │
                        ▼
┌─────────────────────────────────────────────┐
│    CALCULATION OF INCREMENT                  │
│    OF FUEL CONSUMPTION ΔF                    │──S25
│    ΔF = FB·(Pw + Pmgen) − FA·Pw              │
└─────────────────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────┐
        │   Cgen = ΔF / Pgen         │──S26
        └───────────────────────────┘
                        │
                        ▼          ┌─S27
        ╱─────────────────────╲  NO
        ⟨    Pgen ≧ Pth ?     ⟩─────────────────┐
        ╲─────────────────────╱                 │
                 │ YES                           ▼
                 │              ┌──────────────────────────┐──S28
                 │              │    Pgen = Pgen + Δ        │
                 │              └──────────────────────────┘
                 ▼
        ( RETURN )
```

$$\Delta F = FB \cdot (Pw + Pmgen) - FA \cdot Pw$$

$$Cgen = \Delta F / Pgen$$

$$Pgen \geqq Pth ?$$

$$Pgen = Pgen + \Delta$$

FIG.5

```
        ┌─────────────────────────────┐
        │   CALCULATION OF BATTERY    │
        │    CHARGING COST Cchg       │
        └─────────────────────────────┘
                      │
                      ▼
        ┌─────────────────────────────┐
        │    ACQUISITION OF BATTERY   │── S31
        │      TEMPERATURE Tbat       │
        └─────────────────────────────┘
                      │
                      ▼
        ┌─────────────────────────────┐
        │ CALCULATION OF INTERNAL     │
        │        RESISTANCE r         │
        │                             │── S32
        │                             │
        └─────────────────────────────┘
                      │
                      ▼
        ┌─────────────────────────────┐
        │ CALCULATION OF CHARGING     │
        │ POWER Pbat                  │── S33
        │ FOR EACH MG POWER OUTPUT Pgen│
        │ Pbat = Pgen − Preq          │
        └─────────────────────────────┘
                      │
                      ▼
        ┌─────────────────────────────┐
        │ CALCULATION OF CHARGING     │
        │ CURRENT Ibat                │── S34
        │ Pbat = Ibat·(Ibat·r + OCV)  │
        └─────────────────────────────┘
                      │
                      ▼
        ┌─────────────────────────────┐
        │ CALCULATION OF CHARGING     │
        │ LOSS Lbat                   │── S35
        │ Lbat = R·Ibat²              │
        └─────────────────────────────┘
                      │
                      ▼
        ┌─────────────────────────────┐
        │   CALCULATION OF BATTERY    │
        │   CHARGING COST Cchg        │── S36
        │   (Cgen·Pbat) / (Pbat − Lbat)│
        └─────────────────────────────┘
                      │
                      ▼
        ┌─────────────────────────────┐
        │          RETURN             │
        └─────────────────────────────┘
```

Step S32: CALCULATION OF INTERNAL RESISTANCE r (graph of r versus $Tbat$, decreasing curve from origin 0)

Step S33: CALCULATION OF CHARGING POWER Pbat FOR EACH MG POWER OUTPUT Pgen, $Pbat = Pgen - Preq$

Step S34: CALCULATION OF CHARGING CURRENT Ibat, $Pbat = Ibat \cdot (Ibat \cdot r + OCV)$

Step S35: CALCULATION OF CHARGING LOSS Lbat, $Lbat = R \cdot Ibat^2$

Step S36: CALCULATION OF BATTERY CHARGING COST Cchg, $(Cgen \cdot Pbat) / (Pbat - Lbat)$

FIG.6A

Cchg

LOW

Tbat

HIGH

Cref

Pbat

ΔP

FIG.6B

Cchg

Pchgmax

Cref

Pbat

Pbatreq

FIG.6C

Cchg

Cref

Pbat

Pbatreq = 0

BATTERY CHARGE CONTROL APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is based on and claims the benefit of priority from earlier Japanese Patent Application No. 2010-272750 filed Dec. 7, 2010, the description of which is incorporated herein by reference.

BACKGROUND

1. Technical Field

This invention relates to a battery charge control apparatus for a vehicle, where the vehicle is provided with a prime mover driven by using fuel stored in the vehicle, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a secondary battery that stores the electrical energy.

2. Related Art

A known battery charge control apparatus, as disclosed in Japanese Patent Application Publication No. 2006-166639, is adapted to set a power for charging a secondary battery as a function of a maximum power that allows a cost of fuel consumption per unit electrical power to be kept equal to or smaller than a target cost. In general, when a power requirement of a drive wheel is small, an operating point of an engine is shifted to a higher load by increasing a power output of a generator of the vehicle, which leads to enhancement of fuel usage efficiency of the engine. The apparatus as disclosed above is thus operative to increase the power output of the generator to charge the secondary battery when the power requirement of the drive wheel is small.

Meanwhile, when an amount of battery charging power is increased, a battery charging current becomes larger, which will probably lead to an increase in charging loss due to the presence of internal resistance of the battery. According to findings of a study of the inventors of the present application, since the internal resistance of the secondary battery becomes larger as the temperature of the secondary battery decreases in a winter season or the like, the charging loss becomes larger, which leads to a danger that a decrease in fuel utilization efficiency may exceed a benefit of reducing of the fuel consumption in low cost power generation.

In consideration of the foregoing, exemplary embodiments of the present invention are directed to providing a battery charge control apparatus for a vehicle, where the vehicle is provided with a prime mover driven by using fuel stored in the vehicle, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a secondary battery that stores the electrical energy.

SUMMARY

In accordance with an exemplary embodiment of the present invention, there is provided a battery charge control apparatus for a vehicle, where the vehicle is provided with a prime mover driven by using fuel stored in the vehicle, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a secondary battery that stores the electrical energy generated by the power generation means. The apparatus includes: temperature detection means for detecting a temperature of the battery; and battery-charge limiting means for limiting storing of the electrical energy generated by the power generation

means into the battery when the temperature of the battery detected by the temperature detection means is low.

In general, as the temperature of the secondary battery becomes lower, a larger amount of thermal energy (i.e., the charging loss) is generated from the fuel because some of energy generated from the fuel is converted not into electrical energy to be actually stored in the battery, but into waste thermal energy, which may lead to decrease in fuel utilization efficiency. The apparatus in accordance with the above embodiment can suitably suppress the decrease in fuel utilization efficiency by limiting an amount of energy generated from the fuel to be stored as electrical energy in the battery when the temperature of the secondary battery is low.

In accordance with another exemplary embodiment of the present invention, there is provided a battery charge control apparatus for a vehicle, where the vehicle is provided with a prime mover driven by using fuel stored in the vehicle, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a secondary battery that stores the electrical energy generated by the power generation means. The apparatus includes: cost calculation means for calculating a cost that is an amount of fuel consumed by the prime mover to generate the battery charging power used to actually store unit electric power in the battery; upper-limit setting means for setting an upper limit of the cost on the basis of at least one of a state of charge (SOC) of the battery and a power requirement of a load that is supplied with the electrical power from the battery; and battery-charge limiting means for setting the battery charging power such that the cost calculated by the cost calculation means becomes equal to or smaller than the upper limit set by the upper-limit setting means.

There may be a deviation between the charging power for storing the electrical energy in the battery and electrical power actually stored in the battery. More specifically, the deviation increases as the temperature of the battery decreases or the charging current increases, which leads to decrease in fuel utilization efficiency. In the apparatus of the embodiment, the deviation can be quantitatively assessed with the cost, which can be used to calculate the charging power that can suitably suppress decrease in fuel utilization efficiency.

In accordance with still another exemplary embodiment of the present invention, there is provided a battery charge control apparatus for a vehicle, where the vehicle is provided with a prime mover driven by using fuel stored in the vehicle and mechanically-connected to a drive wheel, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a secondary battery that stores the electrical energy generated by the power generation means. The apparatus includes: temperature detection means for detecting a temperature of the battery; and battery charging power setting means for variably setting a battery charging power supplied from the power generation means to the battery to one of three or more discrete values or a continuous value as a function of the temperature of the battery detected by the temperature detection means such that the battery charging power decreases as the temperature of the battery detected by the temperature detection means decreases, while a state of charge (SOC) of the battery, a power requirement of the drive wheel, and a power requirement of a vehicle-mounted component other than the battery, which is supplied with electrical power from the power generation means, are all remaining unchanged.

In general, as the temperature of the battery becomes lower, a larger amount of thermal energy (i.e., the charging loss) is generated from the fuel because some of energy generated

from the fuel is converted not into electrical energy to be actually stored in the battery, but into waste thermal energy, which leads to decrease in fuel utilization efficiency. The apparatus of the embodiment can suitably suppress such decrease in fuel utilization efficiency by limiting storing of the electrical energy generated from the fuel in the battery when the temperature of the battery is low. In particular, since the charging power is discreetly variably set in three or more steps or continuously variably set as a function of the temperature of the battery, it becomes possible to suitably reflect battery charge limiting request as a function of the temperature of the battery.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 schematically shows a secondary-battery charge control apparatus for a parallel hybrid vehicle in accordance with one embodiment of the present embodiment;

FIG. 2 schematically shows a flowchart of a battery charge controlling process;

FIG. 3A schematically shows an EV-traveling region where an EV-traveling condition is met;

FIG. 3B schematically shows a change in reference charging cost C_{ref} associated with a change in SOC of a high-voltage battery;

FIG. 3C schematically shows a calculation process of a charging power requirement P_{batreq};

FIG. 4 schematically shows a flowchart of a calculation process of a power generation cost C_{gen} to be performed in the battery charge controlling process;

FIG. 5 schematically shows a flowchart of a calculation process of a battery charging cost C_{chg} to be performed in the battery charge controlling process;

FIG. 6A schematically shows a change in charging power requirement P_{batreq} associated with a change in battery temperature T_{bat};

FIG. 6B schematically shows a first special case of setting of the charging power requirement P_{batreq}; and

FIG. 6C schematically shows a second special case of setting of the charging power requirement P_{batreq}.

DESCRIPTION OF SPECIFIC EMBODIMENTS

The present invention will be described more fully hereinafter with reference to the accompanying drawings. Like numbers refer to like elements throughout.

FIG. 1 schematically shows a secondary-battery charge control apparatus suitable for a parallel hybrid vehicle in accordance with one embodiment of the present embodiment.

Referring to FIG. 1, the motor generator (MG) 10, which is a vehicle-mounted main component, is mechanically connected to a drive wheel 16 via a continuously variable transmission (CVT) 12 and a differential gear 14. The motor generator 10 is also mechanically connected to an internal-combustion engine 20 via a clutch 18. The clutch 18 is electronically controlled engagement means for performing engagement and disengagement between the motor generator 10 and the engine 20.

The motor generator 10 supplies electrical power to and receives electrical power from a high-voltage battery 28 via the main inverter 22. The high-voltage battery 28 is a lithium-ion secondary battery with a high terminal voltage for example, of 100 V or higher. The main inverter 22 is controlled by an electrical control unit for the motor generator

(MG ECU) 24. The MG ECU 24 controls a controlled variable of the motor generator 10 by operating the main inverter 22.

An electrical control unit for the engine and the transmission (EG/TM ECU) 26 controls a controlled variable of the engine 20 and changes a transmission gear ratio of the transmission 12.

A hybrid electrical control unit (HV ECU) 34 is upstream of the MG ECU 24 and the EG/TM ECU 26. In other words, only the HV ECU 34 receives a request from a user via a user interface. The HV ECU 34 calculates a controlled variable of the motor generator 10 and a controlled variable of the engine 20, for example, on the basis of a detection value of actuation of a brake pedal 40, a detection value of actuation of an accelerator pedal 42, charging and discharging currents of the high-voltage battery 28 detected by a current sensor 36, and a temperature of the high-voltage battery 28 detected by a temperature sensor 38. In addition, the HV ECU 34 transmits a controlled-variable command value (a power requirement or the like) for the motor generator 10 to the MG ECU 24 and a controlled-variable command value (a power requirement) for the engine 20 to the EG/TM ECU 26.

The high-voltage battery 28 is connected to an electrical motor that drives a compressor of an air conditioner (A/C) 32 via the auxiliary inverter 30. For illustrative purpose, a controlling entity that controls the auxiliary inverter 30 is not shown in FIG. 1.

The HV ECU 34 is adapted to determine whether the drive wheel 16 is driven by the motor generator 10 only or by the engine 20. When the engine 20 is used to drive the drive wheel 16, the motor generator 10 may be used to charge the high-voltage battery 28 under a prescribed condition.

FIG. 2 shows a flowchart of a battery charge controlling process to be performed by the HV ECU 34 in accordance with the present embodiment. This process is performed repeatedly at a predetermined time interval.

First, in step S10, a drive power requirement P_w, which is a traveling power of the vehicle, is calculated on the basis of an amount of actuation of the brake pedal 40 and an amount of actuation of the accelerator pedal 42. The drive power requirement P_w is positive when the drive wheel 16 is supplied with positive drive power. Subsequently, in step S12, it is determined whether or not the drive power requirement P_w is larger than a maximum power P_{emax} of the engine 20, thereby determining whether or not the vehicle has to be inevitably supplied with a travelling power from the motor generator 10.

If it is determined in step S12 that the drive power requirement Pw is larger than a maximum power P_{emax} of the engine 20, a command power P_{ecmd} for the engine 10 and a command power P_{mg} for the motor generator 10 are calculated in step S14, where the command power P_{mg} may be set to $P_w - P_{emax}$ and the command power P_{ecmd} may be set to the maximum power P_{emax}. The command power P_{ecmd} is outputted to the EG/TM ECU 26, which in turn controls the engine 20 on the basis of the command power P_{ecmd}. The command power P_{mg} is outputted to the MG ECU 24, which in turn operates the main inverter 22 to control the controlled variable of the motor generator 10 on the basis of the command power P_{mg}.

On the other hand, if it is determined in step S12 that the drive power requirement P_w is equal to or smaller than a maximum power P_{emax} of the engine 20, it is determined in step S16 whether or not the drive power requirement P_w is negative or an EV traveling condition is met. Basically, the EV traveling condition is met within a small region of drive torque requirement of the drive wheel 16 as shown in FIG.

3A. In the EV traveling mode (or motor-driven mode), a larger traveling speed of the vehicle is allowable for a smaller drive torque requirement.

If it is determined in step S16 that the drive power requirement P_w is negative or the EV traveling condition is met, the command power P_{ecmd} for the engine 20 is set to zero and the command power P_{mg} for the motor generator 10 is set to the drive power requirement P_w in step S18.

If it is determined in step S16 that the drive power requirement P_w is not negative and the EV traveling condition is not met, a power generation cost C_{gen} is calculated in step S20. The power generation cost C_{gen} is a cost for generating a unit electric power by the motor generator 10 converting the power of engine 20 into electrical energy. More specifically, the power generation cost C_{gen} (g/kwh) is an increment in fuel consumption of the engine 20 required to generate the unit electric power through the motor generator 10.

FIG. 4 shows a calculation process of the power generation cost C_{gen}.

In the calculation process of C_{gen}, first, a load power requirement P_{req} is acquired in step S21. Basically, the load power requirement P_{req} is a power requirement of a load (auxiliary inverter 30 or the like) directly supplied with electrical power from the high-voltage battery 28. Such a load is not limited to the auxiliary inverter 30, and may be a DC/DC (DC-to-DC) converter that steps down a voltage of the high-voltage battery 28 and outputs it to a low-voltage battery (not shown).

Subsequently, in step S22, a MG power output P_{gen} is tentatively set to the load power requirement P_{req}. In next step S23, a MG power requirement P_{mgen}, which is a power requirement for the motor generator 10 to generate the MG power output P_{gen}, is obtained by dividing the MG power output P_{gen} by a power generation efficiency.

In step S24, there are calculated a specific fuel consumption FA when the power of the engine 20 is the drive power requirement P_w and a specific fuel consumption FB when the power of the engine 20 is the drive power requirement P_w plus the MG power requirement P_{mgen}. As shown in FIG. 4, the specific fuel consumptions may be calculated by using a map defining a correspondence relation between operating points and efficiency information (on specific fuel consumptions) where the operating points are each determined by a torque and a revolution speed of the engine. In FIG. 4, solid lines represent curves of operating points where on each curve the specific fuel consumption is constant, and dashed lines represent curves of operating points where on each curve the power of the engine is constant.

More specifically, in the present embodiment, each of the specific fuel consumptions FA, FB is calculated as a specific fuel consumption on a TM operating line. The TM operating line is defined by minimizing the specific fuel consumption over various revolution speeds of the engine 20 obtained by actuating the transmission 12 while the revolution speed of the drive wheel 16 is being fixed. The specific fuel consumption FA is a specific fuel consumption at an operating point on the TM operating line where the power of the engine 20 coincides with the drive power requirement P_w. The specific fuel consumption FB is a specific fuel consumption at an operating point on the TM operating line where the power of the engine 20 coincides with the drive power requirement P_w plus the MG power requirement P_{mgen}.

Subsequently, in step S25, an increment of fuel consumption of the engine ΔF during transition from the operating

point A to the operating point B can be calculated by the following equation.

$$\Delta F = FB \cdot (P_w + P_{mgen}) - FA \cdot P_w \qquad (c1)$$

In next step S26, the power generation cost C_{gen} when the MG power output P_{gen} is tentatively set to the load power requirement P_{req} is calculated by $\Delta F / P_{gen}$.

In step S27, it is determined whether or not the tentatively-set MG power output P_{gen} is larger than a threshold power Pth which is assumed to be an upper limit of generable electrical power of the motor generator 10, that is, a smaller one of a maximum MG power output of the motor generator 10 and a surplus of power of the engine 20 ($P_{emax} - P_w$). If it is determined in step S27 that the tentatively-set MG power output P_{gen} is smaller than the threshold power Pth, then the MG power output P_{gen} is incremented by a specified amount D in step S28, and the process then returns to step S23. If it is determined in step S27 that the tentatively-set MG power output P_{gen} is equal to or larger than the threshold power Pth, then the process is ended, which is followed by step 30 as shown in FIG. 3.

Returning to FIG. 2, a battery charging cost C_{chg} is calculated in step S30. The battery charging cost C_{chg} is a cost for generating a unit charged power (or unit stored power) by the motor generator 10 converting the power of engine 20 into electrical energy to be charged in the high-voltage battery 28. More specifically, the battery charging cost C_{chg} (g/kwh) is an increment in fuel consumption of the engine 20 required to generate the unit charged power through the motor generator 10.

FIG. 5 shows a calculation process of the battery charging cost C_{chg}.

In step S31 of the C_{chg} calculation process, a temperature T_{bat} of the high-voltage battery 28 detected by the temperature sensor 38 is acquired first. Subsequently, in step S32, an internal resistance r of the high-voltage battery 28 is calculated on the basis of the temperature T_{bat}. In the present embodiment, the internal resistance r is calculated by using a map defining a correspondence relation between the temperature T_{bat} and the internal resistance r previously determined by experiment. In the map, a larger internal resistance r corresponds to a lower temperature T_{bat}.

In next step S33, a battery charging power P_{bat} is calculated for each MG power output P_{gen} tentatively set in the calculation process of the power generation cost C_{gen} as shown in FIG. 4. The charging power P_{bat} is given by subtracting the load power requirement P_{req} from the MG power output P_{gen}. In step S34, there is calculated a battery charging current I_{bat} when the high-voltage battery 28 is charged with the charging power P_{bat}. The charging current I_{bat} is a positive solution to the following quadratic equation.

$$P_{bat} = I_{bat} \cdot (I_{bat} \cdot r + OCV) \qquad (c2)$$

In the above equation (c2), an open circuit voltage (OCV) of the high-voltage battery 28 is used, which can be calculated by using a map on the basis of a state of charge (SOC) of the high-voltage battery 28.

Subsequently, in step S35, a battery charging loss L_{bat} is calculated. The charging loss L_{bat} is given by the internal resistance r multiplied by a square of the charging current I_{bat}. In next step S36, the battery charging cost C_{chg} is calculated for each MG power output P_{gen} tentatively set in the C_{gen} calculation process. The battery charging cost C_{chg} is given by $(C_g \cdot P_{bat}) / (P_{bat} - L_{bat})$, where C_{gen} is the power generation cost for the tentatively set MG power output P_{gen}, P_{bat} is the battery charging power to the tentatively set MG power output P_{gen}, and L_{bat} is the charging loss.

Referring again to FIG. 2, step S30 in FIG. 2 is completed upon completion of step S36 in FIG. 5, which is flowed by step S40. In step S40, a reference charging cost C_{ref} is calculated. The reference charging cost C_{ref} is a parameter (or indicator) indicative of a degree of battery charging request of the high-voltage battery 28. As shown in FIG. 3B, the reference charging cost C_{ref} is such that the reference charging cost C_{ref} takes a larger value for a smaller SOC of the high-voltage battery 28. This means that a degree of battery charging request of the high-voltage battery 28 becomes larger for a smaller SOC of the high-voltage battery 28. In addition, the reference charging cost C_{ref} is such that the reference charging cost C_{ref} takes a larger value for a larger load power requirement P_{req}. This means that, since a larger amount of power is discharged from the high-voltage battery 28 for a larger load power requirement P_{req}, a degree of battery charging request becomes larger for a larger amount of power discharged from the high-voltage battery 28.

In step S42 in FIG. 2, a charging power requirement P_{batreq} is calculated. As shown in FIG. 3C, the charging power requirement P_{batreq} is defined by the largest one of the charging powers P_{bat} that are equal to or smaller than an upper limit of charging power P_{chgmax} for the high-voltage battery 28, whose corresponding battery charging costs C_{chg} calculated on the basis of the respective MG power outputs P_{gen} tentatively set in the C_{gen} calculation process are equal to or smaller than the reference charging cost C_{ref}. FIG. 3C shows, as an example, that the charging power requirement P_{batreq} is defined by the largest one of the two charging powers P_{bat} corresponding to the respective intersection points between the reference charging cost C_{ref} and a curve that connects the battery charging costs C_{chg} calculated on the basis of the respective tentatively set MG power outputs P_{gen}. It should be noted that the upper limit P_{chgmax} is a function of the temperature T_{bat} and the SOC of the high-voltage battery 28.

In step S44 of FIG. 2, the command power P_{mg} for the motor generator 10 and the command power P_{ecmd} for the engine 20 are calculated, where the command power P_{mg} is required to achieve the charging power requirement P_{batreq}. In the present embodiment, since the command power P_{mg} is such that it takes a positive value on the power-running side, the command power P_{mg} is given by $(-1) \cdot (P_{batreq} + P_{req}) /$ (power generation efficiency), which leads to the command power P_{ecmd} given by $P_w - P_{mg}$.

Subsequently to steps S44, S14, S18 in FIG. 2, a transmission gear ratio of the transmission 12 is changed in step S46. When the process proceeds from step S44 to step S46, the transmission gear ratio is set in step S46 such that the operating point corresponding to the MG power output $P_{gen} = P_{batreq} + P_{req}$ can be obtained. Meanwhile, when the process proceeds from step S14 or S18 to step S46, the transmission gear ratio is fixed at a predetermined value.

There will now be explained some advantages of the present embodiment with reference to FIG. 6.

As shown in FIG. 6A, the charging power requirement P_{batreq} decreases gradually as the temperature T_{bat} of the high-voltage battery 28 decreases even with the reference charging cost C_{ref} being unchanged. This is because the internal resistance r increases as the temperature T_{bat} decreases. In other words, as the charging loss L_{bat} increases, the battery charging cost C_{chg}, which is an increment of fuel consumption required for storing a unit electric power in the high-voltage battery 28, increases. Therefore, even if the reference

charging cost C_{ref} is kept at the same level, the charging power requirement P_{batreq} decreases. The battery charging cost C_{chg} can thus be considered to be a parameter (or indicator) indicative of a degree of battery charge limiting request. In addition, since the degree of battery charge limiting request is quantified as a continuous value (in practice, a discretized value due to digital processing), the degree of battery charge limiting request can be suitably expressed as a function of the temperature T_{bat}. Further, since the degree of battery charge limiting request may not be quantified simply as the upper limit of charging power, the charging power requirement P_{batreq} can be calculated such that the degree of battery charging request and the degree of battery charge limiting request can be consistent with each other.

FIG. 6B shows that only the smallest one of the charging powers P_{bat} whose corresponding battery charging costs C_{chg} coincide with the reference charging cost C_{ref} is smaller than the upper limit of charging power P_{chgmax}. In such a case, the charging power requirement P_{batreq} is set to the upper limit P_{chgmax}.

FIG. 6C shows that there is no battery charging cost C_{chg} at or below the reference charging cost C_{ref}. In such a case, the charging power requirement P_{batreq} is set to zero.

SUMMARY OF THE PRESENT EMBODIMENT

(1) In the present embodiment, the battery charging cost C_{chg} is calculated taking into account the charging loss L_{bat}, and the charging power requirement P_{batreq} of the high-voltage battery 28 is set such that the corresponding battery charging cost C_{chg} is equal to or smaller than the reference charging cost C_{ref}, which leads to the battery charging power that can suitably suppress decrease in fuel utilization efficiency.

(2) In the present embodiment, the charging loss L_{bat} is calculated on the basis of the temperature T_{bat} of the high-voltage battery 28, which allows the charging power requirement P_{batreq} to be calculated taking into account the fact that the charging loss L_{bat} increases as the temperature T_{bat} decreases.

(3) In the present embodiment, the charging loss L_{bat} is calculated on the basis of the internal resistance r as a function of the temperature T_{bat} of the high-voltage battery 28. This allows the high-voltage battery 28 to be modeled using an electrical circuit model, which facilitates calculation of the charging loss L_{bat}.

(4) In the present embodiment, a plurality of MG power outputs P_{gen} of the motor generator 10 are tentatively set, and for each MG power output P_{gen} the battery charging cost C_{chg} corresponding thereto is calculated. This allows the charging power requirement P_{batreq} to be set to more suitably reflect the charging loss associated with battery charge.

(5) In the present embodiment, the operating point of the engine 20 for each tentatively set MG power output P_{gen} is limited onto the TM operating line. This allows the battery charging cost C_{chg} to be calculated such that the fuel utilization efficiency is maximized by changing the revolution speed of the engine.

(6) In the present embodiment, the engine 20 is adapted to be mechanically-connected to the drive wheel 16. With this configuration, the revolution speed the engine 20 is liable to be limited by the revolution speed drive wheel 16, which leads to the limited fuel usage efficiency of the engine 20. Therefore, limiting of the operating points onto the TM operating line by using the transmission 12 is of great utility value.

Other Embodiments

There will now be explained other embodiments of the present invention.

(Regarding the Indicator for the Degree of Battery Charge Limiting Request)

In the above embodiment described in detail, a plurality of charging powers P_{bat} are tentatively set in the C_{chg} calculation process (see S20, S30 in FIG. 2).

In some alternative embodiments, for example, a charging power apart from the current charging power by a predetermined amount of power may be tentatively set. If the battery charging cost C_{chg} calculated on the basis of the tentatively set charging power is equal to or smaller than the reference charging cost C_{ref}, then the current charging power is allowed to change to the tentatively set charging power. On the other hand, if the battery charging cost C_{chg} calculated on the basis of the tentatively set charging power is larger than the reference charging cost C_{ref}, then the current charging power is kept unchanged and the charging power to be tentatively set next time is set smaller than the current charging power.

In the above embodiment described in detail, the battery charging cost C_{chg} is calculated as an indicator indicative of the degree of battery charge limiting request.

In some alternative embodiments, for example, an indicator indicative of the degree of battery charge limiting request may be calculated by $(r_{max}-r)/(r_{max}-r_{min})$ ($=$Ind1), where r_{max} is a maximum value of the internal resistance, r_{min} is a minimum value of the internal resistance, and r is the current internal resistance. When the charging power requirement is calculated as an indicator indicative of the degree of battery charging request, the actual charging power may be set to the charging power requirement multiplied by the indicator Ind1. Further in consideration of the fact that the battery charging loss associated with battery charge is proportional to a square of the charging current, it is desirable to take into account the charging current. For example, the indicator indicative of the degree of battery charge limiting request that takes into account the charging current may be given by $((P_{MAX}-Pr)/P_{MAX})^2 \cdot ((r_{max}-r)/(r_{max}-r_{min}))$($=$Ind2), where P_{MAX} is a maximum charging power, Pr is the charging power requirement. In addition, when the fuel utilization efficiency significantly varies with different operating points as in the case of engine, it is more desirable to take into account the fuel utilization efficiency so that the degree of battery charge limiting request becomes larger as the utilization efficiency decreases. For example, the indicator indicative of the degree of battery charge limiting request that takes into account the fuel utilization efficiency may be given by $(E-E_{min})/(E_{max}-E_{min}) \cdot ((P_{MAX}-P_r)/P_{MAX})^2 \cdot ((r_{max}-r)/(r_{max}-r_{min}))$ ($=$Ind3) where E_{max} is a maximum value of the fuel utilization efficiency (an inverse of the specific fuel consumption or the like), E_{min} is a minimum value of the fuel utilization efficiency, and E is a utilization efficiency of the operating point during charging of the battery. In determining the operating points during charging of the battery, a plurality of charging powers are tentatively set such that the charging powers are smaller than the charging power requirement P_r, and for each charging power the corresponding operating point is set in a similar manner as described above regarding the above embodiment. The actual charging power may be given by a maximum power of the charging powers each multiplied by the corresponding indicator of the degree of battery charge limiting request (Ind1, Ind2, or Ind3).

In the above embodiment described in detail, the indicator indicative of the degree of battery charge limiting request is

assumed to take a continuous value. In some alternative embodiments, the indicator may take three or more discrete values.

(Regarding the Indicator for the Degree of Battery Charge Request)

In the above embodiment described in detail, the reference charging cost C_{ref} is calculated on the basis of both the load power requirement P_{req} and the SOC of the battery.

In some alternative embodiments, the reference charging cost C_{ref} may be calculated on the basis of either one of the load power requirement P_{req} and the SOC. The SOC may be replaced with an amount of charge. In further alternative embodiments, an additional input parameter for calculation of the reference charging cost Cref may be included, such as information from a navigation system. When the vehicle is approaching a downhill slope near the present location, a degree of request for power generation accompanied by fuel consumption may be decreased by decreasing the reference charging cost C_{ref}.

In further alternative embodiments, instead of calculating the upper limit of cost (reference charging cost C_{ref}) as described in the above paragraph "Regarding the indicator for the degree of battery charge limiting request", for example, the charging power requirement may be calculated so as to increase with an increasing difference between the current SOC and the SOC when fully charged.

In the above embodiment described in detail, the indicator (or parameter) indicative of the degree of battery charge request is assumed to take a continuous value. In some alternative embodiments, the indicator may take three or more discrete values.

(Regarding the Limitation of the Charging Power)

In the above embodiment described in detail, the charging power is calculated on the basis of the indicator indicative of the degree of battery charging request and the indicator indicative the degree of battery charge limiting request.

In some alternative embodiments, the upper limit of the charging power may be variably set according to whether or not the temperature of the secondary battery is equal to or lower than a specified temperature.

In the above embodiment described in detail where the charging power is calculated on the basis of the indicator indicative of the degree of battery charging request and the indicator indicative the degree of battery charge limiting request (see FIG. 2), it can be found that there exists a one-to-one correspondence between a set of input parameters (the temperature T_{bat}, the SOC, the load power requirement P_{req}, the drive power requirement P_w, the revolution speed of the drive wheel 16) and the charging power requirement P_{batreq}.

In consideration of the finding, in further alternative embodiments, for example, there may be prepared a map defining a correspondence relation between the input parameter set and the charging power requirement P_{batreq}, which can create the same effect as in the above embodiment without performing the calculation of the charging power requirement P_{batreq} on the basis of the indicator indicative of the degree of battery charging request and the indicator indicative of the degree of battery charge limiting request on the HV ECU control unit.

(Regarding Calculation of the Charging Loss)

In the above embodiment described in detail, the charging loss is calculated on the basis of the internal resistance as a function of the temperature of the secondary battery (high-voltage battery 28) where it is assumed that the battery can be modeled in an electrical circuit model.

In some alternative embodiments, for example, a chemical reaction model may be used as a model of the secondary

battery instead of the electrical circuit model as used in the above embodiment, where it is likely that the internal resistance is not used as a linear element. Also in such an embodiment, when a degree of increase in charging loss of the battery associated with decrease in battery temperature can be quantified, it will be possible to calculate the charging loss on the basis of such a chemical reaction model of the battery.

(Regarding Setting of the Operating Points)

In the present embodiment, a set of operating points each specified by a pair of revolution speed and torque of the engine are set such that the specific fuel consumption is minimized at each operating point and the operating points reside over the revolution speed region of the engine **20** feasible through gear-shifting of the transmission **12**.

In some alternative embodiments, for example, a set of operating points each specified by a pair of revolution speed and torque of the engine are set such that the specific fuel consumption is minimized at each operating point and the set of operating points reside over a sub-region within the revolution speed region of the engine **20** feasible through gear-shifting of the transmission **12** where the sub-region consists of the revolution speeds each apart from the current revolution speed by a predetermined amount of revolution speed. Or, only the torque may be increased with the revolution speed being fixed so that the operating point specified by a pair of revolution speed and torque can generate the desired charging power.

(Regarding the Transmission)

In the present embodiment, the transmission is the CVT. In some alternative embodiments, the transmission may be replaced with a stepped variable transmission. In further alternative embodiments, the transmission may be replaced with a planetary gear train that includes a sun gear mechanically connected to a motor generator, a carrier mechanically connected to the engine, and a ring gear mechanically connected to the motor generator and the drive wheel. Also in such an embodiment, the gear ratio may be variably set between the engine and the drive wheel.

In some alternative embodiments, the vehicle may be provided with no transmission (gear-shifting mechanism).

(Regarding the Secondary Battery)

In the above embodiment described in detail, the secondary battery is a lithium-ion secondary battery (high-voltage battery **28**). In some alternative embodiments, the secondary battery may be a nickel-metal-hydride secondary battery or a lead secondary battery.

In the above embodiment described in detail, there is used as a secondary battery the high-voltage battery **28** that is electrically connected to the power converter circuit (main inverter **22**) for supplying electrical power to the vehicle-mounted main component. In some alternative embodiments, only the internal-combustion engine may be a main component, and the secondary battery may be directed to accessories only.

(Regarding the Fuel)

In the above embodiment described in detail, the fuel is fuel that is converted into combustion energy by the internal-combustion engine. In some alternative embodiments, for example, the fuel may be fuel for a fuel cell that supplies electrical power to a vehicle-mounted electrical motor. Advantageously, when the secondary battery needs to be charged by the fuel cell, the battery charging power may be set taking into account a charging loss during charging of the battery as a function of the temperature of the secondary battery.

(Regarding the Prime Mover)

In the present embodiment, the prime mover is a vehicle-mounted main component. In some alternative embodiments, for example, the prime mover may be an internal-combustion engine for a series hybrid car. Also in such an embodiment, when the temperature of the secondary battery is low, the battery charging power is increased, which leads to a larger charging loss and thus to a reduced fuel utilization efficiency. The invention can suppress the decrease in fuel utilization efficiency.

In the above embodiment described in detail, the prime mover is the internal-combustion engine that consumes a fuel. In some alternative embodiments, the prime mover may be a fuel cell as described in the above paragraph "Regarding the fuel".

(Regarding the Power Generation)

In the above embodiment described in detail, rotation energy of the internal-combustion engine (engine **20**) is converted into electrical energy. In some alternative embodiments, for example, waste heat of the internal-combustion engine may be converted into electrical energy.

(Others)

In the above embodiment described in detail, the internal resistance varies with the temperature of the secondary battery (high-voltage battery **28**). Even when the internal resistance is kept constant with the varying temperature of the battery, the battery charging power may be set so as to suppress increase or decrease in charging loss as a function of an amount of charging current.

Many modifications and other embodiments of the invention will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

What is claimed is:

1. A battery charge control apparatus for a vehicle, the vehicle being provided with a prime mover driven by using fuel stored in the vehicle, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a battery that stores the electrical energy generated by the power generation means, the apparatus comprising:

temperature detection means for detecting a temperature of the battery;

battery-charge limiting means for limiting storing of the electrical energy generated by the power generation means into the battery when the temperature of the battery detected by the temperature detection means is low;

first indicator setting means for quantifying a first indicator indicative of a degree of battery charging request as one of three or more discrete values or a continuous value, on the basis of at least one of a state of charge (SOC) of the battery and a power requirement of a load that is supplied with the electrical power from the battery; and

second indicator setting means for quantifying a second indicator indicative of a degree of battery charge limiting request as one of three or more discrete values or a continuous value, on the basis of the temperature of the battery detected by the temperature detection means, wherein:

the battery-charge limiting means variably sets a battery charging power on the basis of both the first indicator

quantified by the first indicator setting means and the second indicator quantified by the second indicator setting means;

the second indicator setting means includes charging loss calculation means for calculating a charging loss that is waste thermal energy generated during storing of the electrical energy in the battery on the basis of the temperature of the battery detected by the temperature detection means, and the second indicator becomes larger for a larger charging loss calculated by the charging loss calculation means;

the second indicator setting means includes cost calculation means for calculating a cost that is an amount of fuel consumed by the prime mover to generate the charging power used to actually store unit electric power in the battery,

the first indicator setting means sets an upper limit of the cost as the first indicator, and

the battery-charge limiting means sets the charging power such that the cost calculated by the cost calculation means becomes equal to or smaller than the upper limit.

2. A battery charge control apparatus for a vehicle, the vehicle being provided with a prime mover driven by using fuel stored in the vehicle, power generation means for converting energy generated by the prime mover using the fuel into electrical energy, and a battery that stores the electrical energy generated by the power generation means, the apparatus comprising:

temperature detection means for detecting a temperature of the battery;

battery-charge limiting means for limiting storing of the electrical energy generated by the power generation means into the battery when the temperature of the battery detected by the temperature detection means is low;

first indicator setting means for quantifying a first indicator indicative of a degree of battery charging request as one of three or more discrete values or a continuous value, on the basis of at least one of a state of charge (SOC) of the

battery and a power requirement of a load that is supplied with the electrical power from the battery; and

second indicator setting means for quantifying a second indicator indicative of a degree of battery charge limiting request as one of three or more discrete values or a continuous value, on the basis of the temperature of the battery detected by the temperature detection means, wherein:

the battery-charge limiting means variably sets a battery charging power on the basis of both the first indicator quantified by the first indicator setting means and the second indicator quantified by the second indicator setting means;

the second indicator setting means includes charging loss calculation means for calculating a charging loss that is waste thermal energy generated during storing of the electrical energy in the battery on the basis of the temperature of the battery detected by the temperature detection means, and the second indicator becomes larger for a larger charging loss calculated by the charging loss calculation means;

the second indicator setting means includes cost calculation means for calculating a cost that is an amount of fuel consumed by the prime mover to generate the charging power used to actually store unit electric power in the battery,

the first indicator setting means sets an upper limit of the cost as the first indicator,

the battery-charge limiting means sets the charging power such that the cost calculated by the cost calculation means becomes equal to or smaller than the upper limit; and

the cost calculation means includes charging power setting means for tentatively setting a plurality of charging powers for storing the electrical energy in the battery, and the cost calculation means calculates the cost for each of the plurality of charging powers.

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